Proceedings of the Iowa Academy of Science

Volume 70 | Annual Issue Article 36

1963

Measurement of Thermal Properties by the Arc Image Furnace

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Measurement of Thermal Properties by the Arc Image Furnace[1]

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Abstract. A number of imaging furnace systems and sources are discussed with emphasis on the carbon arc image furnace. Several potential applications of the carbon arc image furnace in high temperature research are described and a new method of heat capacity determination is discussed.

Advances in high temperature materials during the past few years have created a need for better heating devices. These devices are needed for accurate investigations of thermal properties, reaction kinetics, physical properties, and nuclear parameters. One group of devices which deserves and is receiving considerable emphasis is that of imaging furnace systems.

The purpose of this paper is to illustrate some of the potential imaging furnace systems, to discuss some of the properties that may be determined, and to suggest some further applications utilizing such furnaces.

An imaging furnace is an extremely simple optical system which provides a source of intense heat by the concentration of radiant energy. The major factor controlling the intensity of the radiant flux, the spectral distribution, and the temperature attained is the source which is imaged. The only other contributing factor is the effectiveness of the optical system.

Sources which have a very high radiant energy output include the sun, filament lamps, carbon arcs and plasma jets. Each of these sources has its own characteristic spectral distribution which may or may not be desirable in a particular application. Although any source can be imaged this paper shall discuss in detail the carbon arc image furnace and its utility in high temperature property measurements. The principles involved can be applied to any type of imaging furnace.

Experimental Configurations

Carbon arc image furnace technology has been greatly enhanced by developments in projection lamps and carbons used for motion picture projection. Colored pictures, larger screens, and outdoor theaters have required better reflectors, carbons, lenses, and related apparatus which provide a more uniform and intense light source. The advancements in these two fields are so closely associated that today commercial arc image fur-

[1] Contribution No. 1309. Work was performed in the Ames Laboratory of the U. S. Atomic Energy Commission.

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naces are available which are constructed almost entirely of components developed for motion picture projection.

Carbon arc image furances can be classified by the optics involved in the following manner:

I Single elliptical mirror
II Double elliptical mirror
III Double parabolic mirror
IV Condenser relay lenses

A diagram of these various types and their modifications is given in Figure. 1.

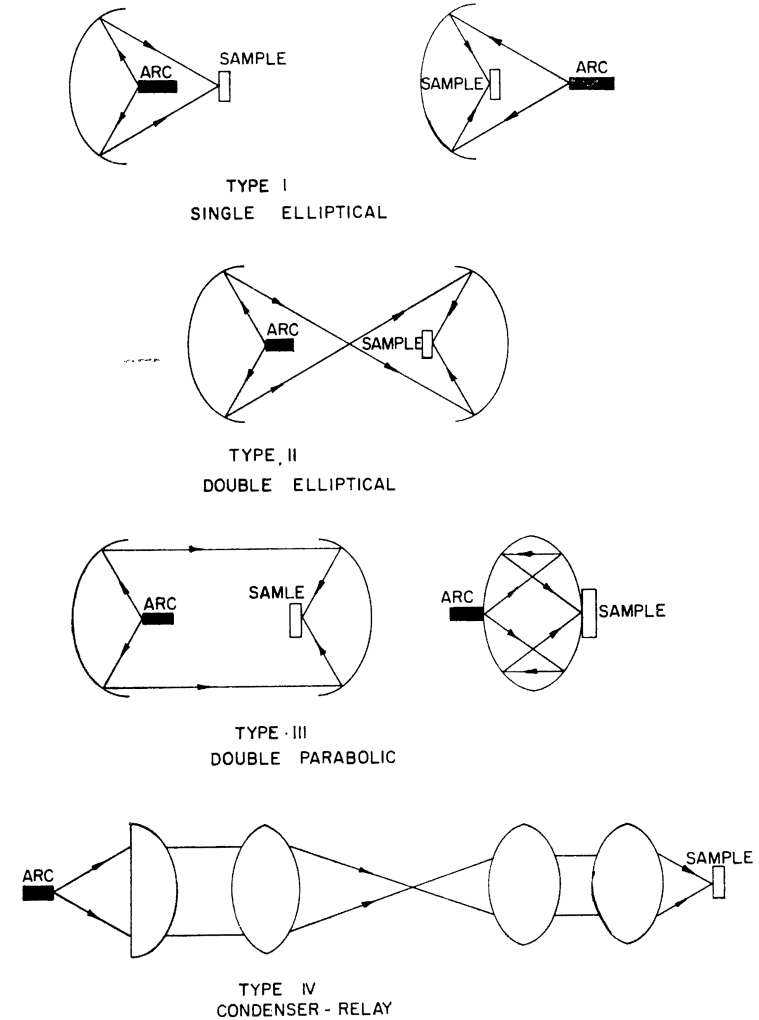


Figure 1 Carbon arc image furnace types.

In all of the above types the flux and temperature of the image is limited by the quality of the optics and by the arc itself. Commercially available lamps will at present develop a flux of approximately 225 cal/cm^2 sec (1). Fluxes as high as 350 cal/cm^2 sec have reportedly been attained utilizing a commercial furnace and experimental positive carbons (2).

Temperature control of the specimen can be attained in several ways. Perhaps the simplest is to move the specimen slightly away from or toward the image which will lower or raise the incident flux. Some control can be achieved by controlling the arc current. Interception of the optical path or a portion thereof by an opaque or translucent medium is shown in Fig. 2.

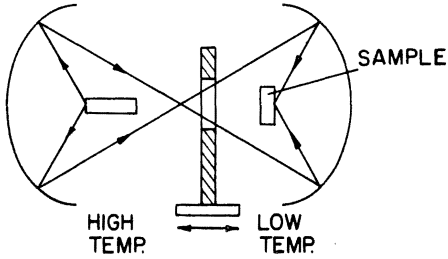


Figure 2 Temperature controlling device.

Another variation of this method is interception of the optical path for very short periods of time by an opaque rotating shutter, giving a pulsating flux. If the frequency of the pulsation is high there is a negligible time variance of the specimen temperature. This method also has the advantage that the pulsating nature of the energy supplied to the specimen enhances amplification in external measuring devices by providing an alternating signal.

The heat energy produced at the specimen position in a carbon arc image furnace is unique in that it is free from electric and magnetic fields, free from products of combustion, can be absorbed by specimen by one mechanism only (radiant heat transfer), and is concentrated in a very small area.

Temperature Measurement

Thermocouples and resistance thermometers are well suited to arc image furnace studies as the concentration of the radiant energy into a small area requires that the specimen be quite small. A small specimen also minimizes thermal gradients and thus leads to accurate temperature determinations with such devices. Difficulties encountered are the limitation on the upper temperature which can be measured and conduction of heat away from the specimen by the electrical leads.

Optical pyrometers are suited only if the specimen is viewed when it is not being irradiated by the furnace. This does not completely rule out the use of optical pyrometers since a system of rotating shutters can be designed such that the specimen is viewed intermittently at times when it is not reflecting radiant energy from the furnace. Corrections can then be made in the pyrometer reading for the effects of the shutters. A serious limitation is the need for spectral emissivity data which are usually not available for the temperatures in question.

The use of total radiation pyrometers is limited in exactly the same way as the use of optical pyrometers. An advantage lies in the fact that total emissivity data are more available than spectral and that total emissivity data can be extrapolated to higher temperatures with less chance for serious error than can spectral emissivity data.

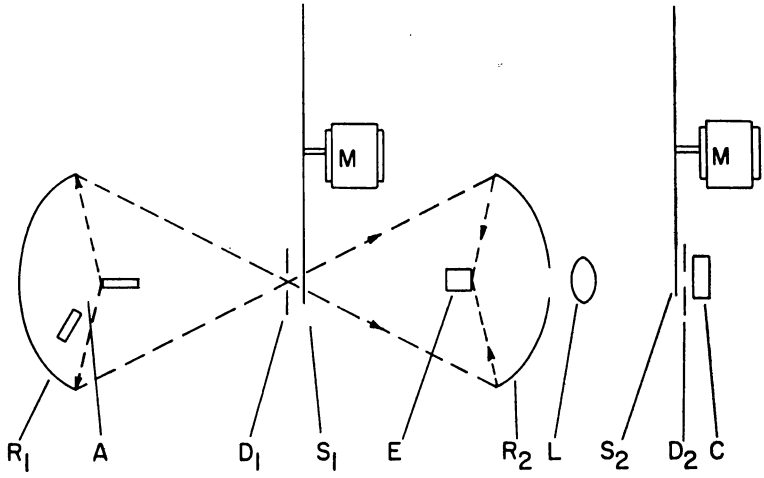
Perhaps the best non-contact pyrometer is the photoelectric type. Such pyrometers have very rapid response times, are quite accurate, and are often designed to perform dichroic pyrometry thus minimizing emissivity errors.

Properties Measured

Among the many high temperature thermal properties which can be measured with a carbon arc image furnace, one of the more obvious is spectral emissivity. An example is a method to measure the emissivity of graphite at 3800°K (3) as given in Figure. 3.

The specimen is a standard pyrometric arc employing spectroscopic electrodes having a temperature very close to 3800°K. The synchronous shutters which can be shifted 90° in phase are used to separate the emitted and reflected radiation from the standard arc. When the shutters are in phase the photoelectric cell receives a pulsating signal composed of both reflected and emitted radiation. When out of phase the detector receives a pulsating signal composed of only emitted radiation. The difference of the output of the cell under these conditions yields a measure of the energy reflected by the standard pyrometric arc. The ratio of this energy to the energy reflected by a standard reflector (freshly prepared magnesium oxide surface) gives the absolute reflectivity of the graphite of the arc. Kirchoff's law, $1 - r = \varepsilon$ (where r = reflectivity and $\varepsilon \equiv$ emissivity) can then be applied to yield emissivity.

A device used by the authors differs from the above in that no shutters are involved. The temperature of the specimen is measured with a thermocouple and both the energy emitted by the specimen and that reflected by it fall upon the photocell. The brightness temperature response of the photocell is cali-



A-IMAGE FURNACE ARC
D_1, D_2-DIAPHRAGMS
S_1, S_2-SYNCHRONOUS SHUTTERS
L-LENS
C-PHOTOCELL
E-EXPOSED SAMPLE
M-MOTOR
R_1, R_2-FURNACE REFLECTORS

Figure 3 Apparatus for determination of reflectance and emissivity of graphite.

brated against a standard tungsten filament lamp. Spectral measurements are facilitated by using spectral filters directly in front of the photocell as shown in Fig. 4. When the emitted plus reflected radiant energy issuing from the specimen is compared to the reflected radiant energy from a standard reflector the emissivity of the specimen may be calculated by Kirchoff's law and a method of successive approximations. The steps involved in this solution are:

$$\begin{aligned} r_1 &= R + E/R_s & \varepsilon_1 &= 1 - r_1 \\ r_2 &= R + E - \varepsilon_1 KT/R_s & \varepsilon_2 &= 1 - r_2 \\ r_n &= R + E - \varepsilon_{n-1} KT/R_s & \varepsilon_n &= 1 - r_n \end{aligned} \qquad [1]$$

where:

r_n=nth approximation of reflectivity
ε_n=nth approximation of emissivity
T=temperature of the specimen

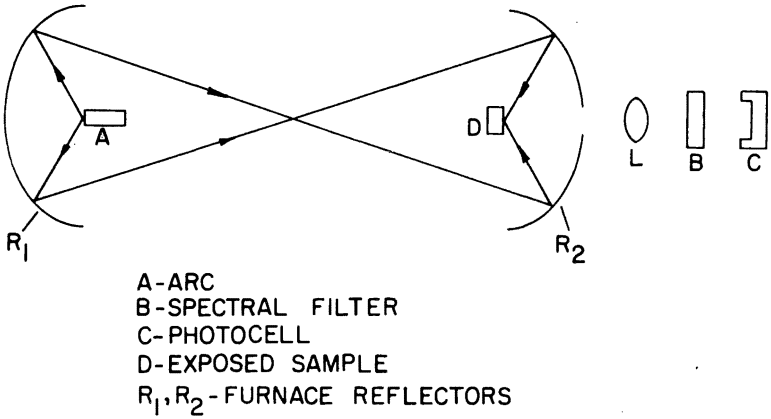


Figure 4 Apparatus for spectral emissivity measurement.

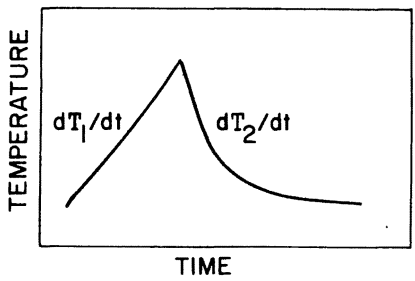
R+E=reflected plus emitted energy of the specimen at temperature T

R_s=energy reflected by standard reflector

K=brightness temperature response coefficient of the photocell.

Emissivity data at five different wavelengths in the visible spectrum over the temperature range of 200 to 1600°C have been given for several ceramic oxides (4).

Solar absorptance and total emittance of real surfaces have also been determined using a carbon arc image furnace (5). The heating and cooling curves of a specimen irradiated by a carbon arc image are monitored in an isothermal, evacuated blackbody chamber (see Fig. 5).



dT_1/dt = SLOPE HEATING CURVE

dT_2/dt = SLOPE COOLING CURVE

Figure 5 Plot of heating and cooling curves used in solar absorptance and total emissivity determinations.

The spectral distribution of a carbon arc is quite similar to that of the sun and the solar absorptance and total emissivity of the specimen are given by the following relationships:

$$\alpha = \frac{mC_p(dT_1/dt - dT_2/dt)}{A_1H} \quad [2]$$

$$\varepsilon_{th} = \frac{mC_p(dT_2/dt)}{A_2\sigma(T^4 - T_o^4)} \quad [3]$$

where:

α=solar absorptance
ε_{th}=total hemispherical emissivity
m=mass of the specimen
A_1=area of specimen illuminated by the furnace
A_2=total area of the specimen
H=irradiance of the furnace
T=temperature of the specimen
T_o=temperature of blackbody walls
σ=Stefan-Boltzmann constant
C_p=specific heat of specimen at temperature T
dT_1/dt=slope of heating curve at temperature in question
dT_2/dt=slope of cooling curve at temperature in question.

The success of this method depends upon the occurrence of

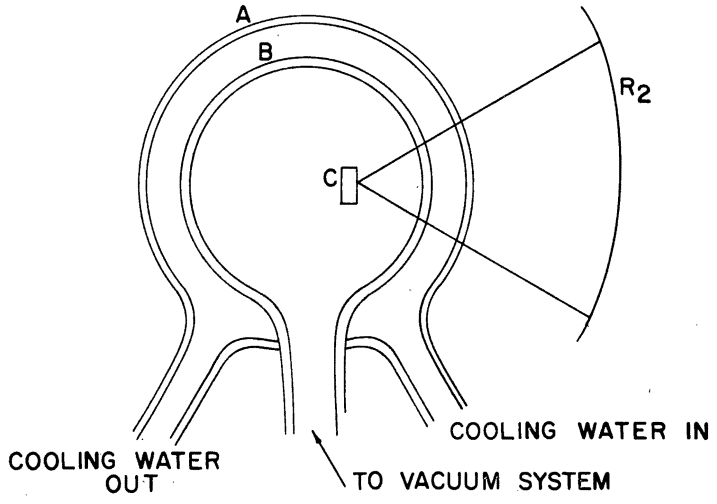


Figure 6 Isothermal chamber used in heat capacity measurement.

only radiant heat transfer. Thus precautions must be taken to eliminate convective or conductive losses.

A carbon arc image furnace has also been used to measure high temperature thermal diffusivity of metals (6). The temperature rise at two points in a cylindrical specimen, mounted to simulate a portion of an infinite slab, is measured during the time one surface of the specimen is being heated by the furnace. From the changes in the temperatures at the front and back of the specimen the thermal diffusivity may be calculated.

Heat capacity studies are also well suited to the carbon arc image furnace (7) (see Figure. 6).

The spectral distribution of a carbon arc is concentrated in the visible portion of the spectrum and the spectral distribution of radiant energy emitted by specimens at temperatures even as high as 2000°K is concentrated in the infrared. Since this is true the evacuated chamber of Fig. 6 acts as a blackbody to the radiation emitted by the heated specimen (i.e. to infrared radiation) but the combination glass-water window is transparent to the visible portion of the spectrum thus allowing the specimen to be heated by a carbon arc image furnace.

The specimen is heated in the chamber shown in Fig. 6, the arc is turned off, and the cooling curve of the specimen is monitored. Equation (3) may be rewritten:

$$C_p = \frac{mdT/dt}{\varepsilon_{ht} A\sigma(T^4 - T_o^4)}.$$

Thus the heat capacity is proportional to the slope of the cooling curve. Solution of the proportionality factor depends upon a knowledge of the total hemispherical emissivity. This restriction can be eliminated by coating the specimen with a very thin black coating such as platinum black to give it an emissivity of unity, or the emissivity may be measured separately by other means previously discussed.

Ignition is also amenable to analysis utilizing an arc image furnace (8). Ignition of solid fuels requires a certain threshold energy. When less than this amount is absorbed ignition does not occur. A carbon arc image furnace can supply a constant amount of energy per unit time to such a material and by varying the time of exposure the threshold energy can be determined. Also the variables affecting ignition such as environment, pressure, past history and surface conditions can be easily studied.

Oxidation studies (9) are also possible with the arc image furnace. The constant energy input and the ease of controlling atmospheres make the utility of the apparatus in this field obvious.

Melting point determination with a carbon arc image furnace is unique in that there is no container problem. Since the energy of the furnace is concentrated in a small area the specimen forms its own container eliminating a common source of error.

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A One-Day Modification of the Dry Ash PBI Method

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with the technical assistance of Donna Douglas

Abstract. A modification of the dry ash method for the protein bound iodine content of plasma or serum has been devised. This method permits completion of the determination in one laboratory day and produces results that compare favorably with the original two-day method. Recovery experiments were satisfactory and indicate no loss of iodine in the drying, ashing, or colorimetric procedures in the method.

A method commonly employed for the analysis of the protein bound iodine content of serum or plasma was devised by Barker, et al, in 1950. The procedure was developed in this university and in modified form has been used in our clinical protein bound iodine laboratory since its inception. The method essentially consists of the precipitation of the plasma or serum proteins, washing of the precipitate, drying in the presence of sodium carbonate, ashing, dissolving the ash in an acid solution and colorimetrically measuring the disappearance of the color of ceric ammonium sulfate in the presence of sodium arsenite. Although many modifications of the method have been proposed, the time consuming overnight drying of the precipitate in the presence of sodium

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